

component are preferably determined empirically for each specific CMP process by measuring the temperature of the component during polishing of a known intermediate surface 157 on a substrate and a known finished surface 157(a) on a like substrate and under like operating parameters. The actual tests to empirically determine the first and second temperatures of a given polishing component for a specific CMP process may vary and are generally known to persons skilled in the art of CMP.

The preferred embodiment of the polishing machine 110 may also be used to endpoint the CMP process at a level below the top of the underlying layer 154 because the heat  $H_2$  at the pad/substrate interface 160 also varies with the extent to which the underlying layer 154 is exposed to the polishing medium. It will be appreciated that the change in heat between the first and second heats  $H_1$  and  $H_2$  is also a function of the surface area of the underlying layer 154 that is exposed to the polishing medium. In many polishing processes, one area of the wafer polishes faster than another so that only a fraction of the underlying layer 154 at the finished surface 157(a) is initially exposed to the polishing medium. As polishing progresses, more material is removed from the cover layer 156 to expose more of the underlying layer 154. As a result, the change in heat when the underlying layer 154 is initially exposed to the polishing medium is often different than at subsequent points in the polishing process when a different percentage of the exposed surface area on the substrate 150 is composed of the underlying layer 154. In a preferred embodiment, therefore, the heat sensors 170 indicate that the polishing process is at the desired endpoint when the temperature indicates that the heat  $H_2$  at the pad/substrate interface 160 corresponds to a heat at which a sufficient percentage of the surface area on the wafer is composed of the underlying layer 154.

In another embodiment of the invention, a reactive agent is added to the slurry or planarizing liquid 148 to increase the difference between the heats  $H_1$  and  $H_2$  at the pad/substrate interface 160. The particular reactive agent is selected according to the materials of the underlying layer 154, the cover layer 156, and the composition of the planarizing liquid 148. In one embodiment, the reactive agent is HCl,  $\text{NH}_4\text{OH}$  or KOH for use with an underlying layer 154 made of tungsten, a cover layer 156 made of silicon dioxide and an  $\text{H}_2\text{O}_2$  based planarizing liquid 148 manufactured by Rodel Corporation of Newark, Del.

A preferred embodiment of the present invention accordingly provides fast, real-time direct monitoring of the polishing status of the substrate 150. Unlike conventional endpointing techniques that remove the substrate from the polishing pad to measure a change in the thickness of the substrate, a preferred embodiment of the present invention determines the endpoint in-situ and in real-time without removing the substrate from the polishing pad and without stopping the polishing process. A preferred embodiment of the present invention, therefore, is expected to accurately endpoint CMP processing without adversely affecting the throughput of finished substrates.

Another advantage of a preferred embodiment of the present invention is that it accurately determines the endpoint of the polishing process even though the polishing parameters may change from one substrate to the next. As discussed above in the Background section, the polishing rate of a run of substrates may change from one substrate to the next for several reasons. A preferred embodiment of the present invention is expected to accurately indicate the endpoint of the polishing process even though one or more of the polishing parameters changes from one wafer to the next because the change in heat at the pad/substrate interface 160 is a function of the composition of the planarized surface on the substrate that is exposed to the polishing

medium. Therefore, it is expected that a preferred embodiment of the present invention will increase the accuracy of stopping CMP processing at a desired endpoint.

FIG. 4 is a schematic cross-sectional view of another embodiment of a polish machine 210 for polishing the substrate 150. As discussed above with respect to FIG. 2, the polish machine 210 has a housing 112, a platen 120, a substrate carrier assembly 130, and a polishing pad 140. The polish machine 210 also has a reacting cell 220 preferably positioned in the housing 112, and a feed line 230 from the cell 220 to the CMP byproducts 148(a) on the platen 120. The feed line 230 is preferably movable so that it can be removed from the byproducts 148(a) and/or the interior of the platen 120 during planarization when the platen 120 rotates. In operation, the CMP byproducts 148(a) are pumped through the feed line 230 and into the cell 220 by a pump (not shown). Once a sufficient volume of CMP byproducts 148(a) is pumped into the cell 220, a reactive agent 240 is mixed with the CMP byproducts 148(a) to detect whether material of the underlying layer 154 is present in the CMP byproducts 148(a). The reactive agent 240 is preferably selected to react with the material of the underlying layer 154 in a manner that indicates the quantity of the underlying layer 154 that is present in the CMP byproducts 148(a).

Many different reactive agents 240 may be added to the cell 220 to indicate the presence and quantity of material from the underlying layer 154 in the CMP byproducts 148(a). Depending upon the specific reactive agent 240, the resulting reaction may be detected by a change in temperature in the cell 220 measured by a heat sensor 170(d), a change in color of the reacted CMP byproducts 148(a) in the cell 220, or other known techniques to monitor chemical reactions. One suitable reactive agent 240 to detect the presence of tungsten or compounds of tungsten in the CMP byproducts 148(a) is composed of potassium chlorate ( $\text{KClO}_3$ ) and aqua regia ( $\text{HCl}+\text{HNO}_3$ ).

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. For example, the heat at the front of the substrate is only one characteristic of a polishing component indicative of material being removed from the planarized surface of the substrate. When the polishing component is the CMP byproducts, the characteristics of the byproducts that may be indicative of the material at the front face of the substrate include the pH of the byproducts, the conductivity of the byproducts (especially for polishing conductive layers), the color of the byproducts, and the chemical composition of the byproducts. Predetermined values of any characteristic corresponding to the endpoint may be determined in a similar manner as described above with respect to the temperature of a polishing component sensitive to the heat at the front face of the substrate. For example, the pH level of the byproducts may be determined using a calomel electrode known in the art, or the chemical composition of the byproducts may be determined by infrared spectroscopy, elemental analysis, or atomic absorption processes known in the art. Accordingly, the invention is not limited except as by the appended claims.

I claim:

1. A method for stopping polishing of a substrate at a desired endpoint, the substrate having a cover layer and an underlying layer under the cover layer, the method comprising:

monitoring a characteristic of a polishing component indicative of material being removed from a planarized surface of the substrate, wherein the component comprises byproducts produced by polishing the substrate

and the characteristic is a temperature of the byproducts, and wherein the monitoring step comprises sensing the temperature of the byproducts; and

stopping removal of material from the substrate when the characteristic of the polishing component is at a predetermined value that indicates the material being removed from the planarized surface is at the desired endpoint of the substrate.

2. The method of claim 1 wherein the sensing step comprises measuring a temperature of a planarizing liquid flowing off of a polishing pad.

3. A method for stopping mechanical and chemical-mechanical polishing of a substrate at an endpoint, the substrate having a cover layer and an underlying layer under the cover layer, and the method comprising:

monitoring heat transfer at a planarized surface of the substrate and a polishing component sensitive to heat at the planarized surface by measuring a temperature of the component, and wherein measuring the component temperature comprises sensing a temperature of byproducts produced by polishing the substrate; and

stopping polishing of the substrate when the characteristic of the polishing component is at a predetermined value that indicates the planarized surface is at the desired endpoint.

4. The method of claim 3 wherein the sensing step comprises measuring a temperature of a planarizing solution flowing off of the polishing pad.

5. A method for stopping mechanical and chemical-mechanical polishing of a substrate at an endpoint, the method comprising:

detecting a change in heat at a front side of the substrate, the heat at the front side of the substrate being different when a cover layer of the substrate engages a polishing medium than when at least a portion of an underlying layer of the substrate under the cover layer engages the polishing medium, wherein detecting a change in heat at the front side of the substrate comprises sensing a temperature of byproducts produced by polishing the substrate; and

stopping removal of material from the substrate when the heat is a predetermined value that indicates a desired portion of the underlying layer is exposed at the front side of the substrate.

6. The method of claim 5 wherein the sensing step comprises measuring a temperature of a planarizing solution flowing off of the polishing pad.

7. A method for stopping mechanical and chemical-mechanical polishing of a substrate at an endpoint, the method comprising:

measuring a temperature of a component sensitive to heat at a front side of the substrate, the component temperature being different when a cover layer of the substrate engages a polishing medium than when a portion of an underlying layer of the substrate under the cover layer engages the polishing medium, wherein measuring the component temperature comprises sensing a temperature of byproducts produced by polishing the substrate; and

stopping removal of material from the substrate when the component temperature changes from the first temperature range to the second temperature range.

8. A method of polishing a substrate, comprising:

removing material from a front side of the substrate with a polishing medium, the polishing medium being positioned at a planarizing surface of a polishing pad;

monitoring heat at the front side of the substrate, the heat at the front side of the substrate being different when a cover layer of the substrate engages the polishing medium than

when at least a portion of an underlying layer of the substrate under the cover layer engages the polishing medium, wherein monitoring the heat comprises measuring a temperature of a component sensitive to heat at the front side of the substrate, the component temperature being a first temperature when the cover layer of the substrate engages the polishing medium and the component temperature being a second temperature when at least a portion of the underlying layer of the substrate engages the polishing medium, and wherein measuring the component temperature comprises sensing a temperature of byproducts produced by polishing the substrate; and

stopping removal of material from the substrate when the heat at the front side of the substrate is a predetermined value that indicates a desired portion of the cover layer has been removed from the substrate.

9. The method of claim 8 wherein the sensing step comprises measuring a temperature of a planarizing solution flowing off of the polishing pad.

10. A method of polishing a substrate, comprising:

removing material from a front side of the substrate with a polishing medium, the polishing medium being positioned at a planarizing surface of a polishing pad;

detecting a change in heat at the front side of the substrate, the heat at the front side of the substrate being in a first range when a cover layer of the substrate engages the polishing medium and the heat being in a second range when a portion of an underlying layer of the substrate under the cover layer engages the polishing medium, wherein detecting the change in heat comprises measuring a temperature of a component sensitive to heat at the front side of the substrate, the component temperature being in a first temperature range when the heat at the front side of the substrate is in the first heat range and the component temperature being in a second temperature range when the heat at the front side of the substrate is in the second heat range, and wherein measuring the component temperature comprises sensing a temperature of byproducts produced by polishing the substrate; and

stopping removal of material from the substrate when the heat at the front side of the substrate is in the second range.

11. The method of claim 10 wherein the sensing step comprises measuring a temperature of a planarizing solution flowing off of the polishing pad.

12. A method of polishing a substrate, comprising:

removing material from a front side of the substrate with a polishing medium, the polishing medium being positioned at a planarizing surface of a polishing pad;

measuring a temperature of a component sensitive to heat at the front side of the substrate, the component temperature being different when a cover layer of the substrate engages the polishing medium than when at least a portion of an underlying layer of the substrate under the cover layer engages the polishing medium, wherein measuring the component temperature comprises sensing a temperature of byproducts produced by polishing the substrate; and

stopping removal of material from the substrate when the component temperature changes from the first temperature range to the second temperature range.

13. The method of claim 12 wherein the sensing step comprises measuring a temperature of a planarizing solution flowing off of the polishing pad.